

**NJCAT TECHNOLOGY VERIFICATION**

**HYDROGLOBE**

**June, 2002**

## TABLE OF CONTENTS

1.	Introduction .....	3
1.1	NJCAT Program .....	3
1.2	Technology Verification Report .....	4
1.3	Technology Description .....	4
1.3.1	Technology Status .....	4
1.3.2	Specific Applicability .....	5
1.3.3	Range of Contaminant Characteristics .....	6
1.3.4	Treatability Studies .....	6
1.4	Project Description .....	7
1.5	Key Contacts .....	7
2.	Evaluation of the Applicant .....	8
2.1	Corporate History .....	8
2.2	Organization and Management .....	8
2.3	Operating Experience with respect to the Proposed Technology .....	8
2.4	Patents .....	9
2.5	Technical Resources Staff and Capital Equipment .....	9
3.	Treatment System Description .....	9
4.	Technical Performance Claim .....	10
5.	Treatment System Performance .....	10
5.1	Field Pilot Demonstration .....	10
5.2	Field Demonstration .....	11
5.3	Verification Procedures .....	12
6.	Technical Evaluation Analysis .....	17
6.1	Verification of Performance Claims .....	17
6.2	Limitations .....	17
7.	Net Environmental Benefit .....	17
8.	Costs .....	20
9.	References .....	21
	Appendix – Capital and Operating Costs .....	22
	Figure 1 – Environmental Fate of Arsenic With/Without FerriMet Process .....	23

## 1. Introduction

### 1.1 NJCAT Program

NJCAT is a not-for-profit corporation to promote in New Jersey the retention and growth of technology-based businesses in emerging fields such as environmental and energy technologies. NJCAT provides innovators with the regulatory, commercial, technological and financial assistance required to bring their ideas to market successfully. Specifically, NJCAT functions to:

- Advance policy strategies and regulatory mechanisms to promote technology commercialization
- Identify, evaluate, and recommend specific technologies for which the regulatory and commercialization process should be facilitated
- Facilitate funding and commercial relationships/alliances to bring new technologies to market and new business to the state, and
- Assist in the identification of markets and applications for commercialized technologies.

The technology verification program specifically encourages collaboration between vendors and users of technology. Through this program, teams of academic and business professionals are formed to implement a comprehensive evaluation of vendor specific performance claims. Thus, vendors have the competitive edge of an independent third party confirmation of claims.

NJCAT has developed and published Technical Guidance Documents containing a technology verification protocol that is consistent with the New Jersey Department of Environmental Protection (NJDEP) Technical Manual and the Interstate Technology and Regulatory Cooperation (ITRC) program technical and regulatory documents. This technology verification review is consistent with the NJCAT general verification protocol contained in the guidance documents.

Pursuant to N.J.S.A. 13:1D-134 et seq. (Energy and Environmental Technology Verification Program) NJDEP and NJCAT have established a Performance Partnership Agreement (PPA) whereby NJCAT performs the technology verification review and NJDEP certifies the net beneficial environmental effect of the technology. In addition, NJDEP/NJCAT work in conjunction to develop expedited or more efficient timeframes for review and decision-making of permits or approvals associated with the verified/certified technology.

The PPA also requires that:

- The NJDEP shall enter in reciprocal environmental technology agreements concerning the evaluation and verification protocols with the United States Environmental Protection Agency, other local required or national environmental agencies, entities or groups in other states and New Jersey for the purpose of encouraging and permitting the reciprocal acceptance of technology data and information concerning the evaluation and verification of energy and environmental technologies; and

- The NJDEP shall work closely with the State Treasurer to include in State bid specifications, as deemed appropriate by the State Treasurer, any technology verified under the energy and environment technology verification program.

## 1.2 Technology Verification Report

In November, 2001, HydroGlobe, 612 River Street, Hoboken, New Jersey, 07030 submitted a formal request for participation in the NJCAT Technology Verification Program. The technology proposed - a direct coprecipitation filtration process, described in greater detail later in this report, is a technology designed to remove heavy metals from water to trace levels. The request after pre-screening by NJCAT staff personnel (in accordance with the technology assessment guidelines) was accepted into the verification program. This verification report covers the evaluation based upon the performance claim of the vendor HydroGlobe (see Section 4). Several meetings were held with the vendor and a number of telephone discussions were conducted to solicit relevant materials and to refine the performance claim. In addition, visits were made to Hopewell, NJ, to observe filtration tests designed to verify the removal of arsenic from groundwater during December, 2001. The evaluation is based on HydroGlobe's laboratory treatability testing and third party certified laboratory reports on the Hopewell demonstration.

## 1.3 Technology Description

### 1.3.1 Technology Status: general description including elements of innovation/uniqueness/competitive advantage.

Arsenic removal technologies can be grouped into four broad categories: precipitative processes, adsorption processes, ion exchange processes, and separation (membrane) processes. HydroGlobe's **FerriMet** process (patent pending) is a precipitative treatment process based on coagulation/filtration.

Coagulation/filtration is a treatment process by which the physical or chemical properties of colloidal or suspended matter are altered such that agglomeration is enhanced to an extent that the resulting particles will settle out of solution by gravity or will be removed by filtration. Coagulants change surface charge properties of solids to allow agglomeration and/or enmeshment of particles into a flocculated precipitate. As a result, the final products are larger particles, or floc, which more readily filter or settle under the influence of gravity. Major components of a coagulation/filtration treatment process include chemical feed systems, mixing equipment, settling/filter media, filter backwash equipment, and sludge handling equipment.

Arsenite [As(III)] removal during coagulation with alum, ferric chloride, and ferric sulfate has been shown to be less efficient than arsenate [As(V)] under comparable conditions. If a high concentration of As(III) is present, oxidation to convert As(III) to As(V) species prior to coagulation should be considered. Also, the presence of anions (e.g., silicate, sulfate, phosphate, carbonate) in the water can affect the efficiency of arsenic removal (Meng, et al., 2000).

## FerriMet Treatment Process

The FerriMet process involves injection of small amounts of coagulants (and oxidants if needed) such as ferric chloride into water and subsequent filtration. The system consists of mainly a sand filter and a chemical pump(s). The process is designed to remove heavy metals (e.g., arsenic, selenium, chromium, lead, and cadmium) from water to trace levels. Ferric chloride injected into the water hydrolyzes rapidly to form ferric hydroxide. The fresh hydroxide has a high capacity for removal of arsenic and other heavy metals through coprecipitation and adsorption. Arsenic is converted from soluble to particulate forms and is subsequently removed by the sand filter. The filters are regenerated by backwash using treated water. The backwash cycle can be triggered by a pressure drop across the filter or by a timer.

The sand filter has a dual function in that it continuously promotes arsenic precipitation in the bed while filtering particulates from the water. While the ferric hydroxide forms rapidly following ferric chloride injection, not all of the dissolved arsenic is removed in the water lines. The FerriMet process also involves activation of the sand filter with small amounts of adsorbent; remaining arsenic is removed in the sand filter/reactor. This polishing effect in the sand filter increases arsenic removal efficiencies, results in a compact treatment facility, and minimizes backwash requirements.

The FerriMet process offers a cost-effective solution to arsenic removal compared to conventional iron-based coagulation processes and filtration treatment using activated alumina and ion exchange resins. Regeneration of activated alumina and ion exchange resins produces large amounts of basic and brine solutions with high concentrations of arsenic that are more difficult to manage (i.e., dispose) than the arsenic containing sludge produced in the coagulation process. The FerriMet process takes a much smaller footprint area than conventional water treatment processes and can remove arsenic to low levels. The technology generates minimal residue, uses additive non-toxic chemicals, and has a low cost of ownership. Since the process can be fully automated, it is especially suitable for small water treatment facilities and for treatment of source water with low turbidity.

### 1.3.2 Specific Applicability

In response to the 1974 Safe Drinking Water Act, the US Environmental Protection Agency (USEPA) was authorized to identify an interim standard for arsenic in drinking water of 50 µg/L. In light of new data concerning the toxicology of arsenic, the Safe Drinking Water Act amendments of 1996 (PL 104-182) required USEPA to proposed a new standard. In January, 2001, USEPA revised the arsenic standard down to 10 µg/L (by 2006) with an effective date of February 22, 2002. New Jersey proposed to adopt the new Federal standard, but chose to implement it 14 months after the effective date of the amendment.

Surface water sources rarely have arsenic concentration > 5 µg/L, whereas 16-46 percent of groundwater sources exceed this value, depending on the region of the country (Chwirka, et al., 2000). Of groundwater sources with elevated arsenic concentrations, most are located in the western United States. In New Jersey, groundwater arsenic concentrations rarely exceed 40 µg/L.

The FerriMet direct coprecipitation filtration process is applicable throughout the United States. However, depending on the water quality and arsenic concentration, pretreatment and multiple treatment units may be required to reduce arsenic concentration to the desired level.

### 1.3.3 Range of Contaminant Characteristics

Since the development of the FerriMet process, full-scale units have been used for the removal of arsenic at two environmental remediation sites in TX and WA. Numerous treatability studies have been conducted to establish optimal treatment conditions such as iron dose and pH for the removal of arsenic from groundwater samples in seven states. The results shown in Table 1 demonstrate that the FerriMet process effectively removed arsenic concentrations from various groundwaters to less than 5 ppb. (Note: The detection limit of arsenic reported by the treatment plant in Bryan, TX was 20 ppb and by the Washington treatment plant, 10 ppb.)

Table 1. List of Groundwaters Treated with the FerriMet Process (Meng, 2002)

	TX Bryan	NJ	NH	NV Walker	NV Fallon	CA Sacramento	NV Fernley	WA
Water Chemistry								
Total As (ppb)	130-500	33-40	73	74	123	49	48	10,000
As(III) (ppb)	<3	<3	<3	<3	<3	34	NA	<3
PH	6.5-7.3	7.6	7.2	7.5	8.6	7.7	7.3	8-9
SiO <sub>2</sub> (ppm)	NA	19	14	55	27	50	44	NA
P (ppm)	NA	NA	0.02	0.05	0.3	NA	NA	NA
Treatment Processes and Arsenic Removal								
Treatment	Full scale	Pilot	Column	Batch	Batch	Batch	Batch	Full Scale
pH adjustment	No	No	No	No	Yes	No	No	No
Oxidation	No	No	No	No	No	Yes	No	No
Iron coagulant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Effluent As, ppb	<20*	<5	<5	2	<5	<3	<3	<10*

\*Detection limit at the plant. NA – Not available.

### 1.3.4 Treatability Studies

Laboratory batch and column tests and field pilot filtration tests are usually performed before the installation of a FerriMet system at a site. Water samples are shipped to HydroGlobe's laboratory for batch and column tests in order to determine if preoxidation and pH adjustment are required. Optimal iron dose is established with these laboratory tests. Based on the laboratory results, the efficiency of arsenic removal will be determined. The FerriMet system is then customized and the capital and operational costs estimated. Field pilot filtration tests are usually conducted to further test the design parameters, since As(III) can be oxidized to As(V) during shipment of the water samples from the field to the laboratory and carbon dioxide will evaporate from the groundwater, which influences the water pH. Therefore optimization of the FerriMet system occurs in the field during start up.

## 1.4 Project Description

This project involved the evaluation of a laboratory groundwater treatability/pilot study and one field demonstration to verify that the FerriMet process meets HydroGlobe's claim.

## 1.5 Key Contacts

Rhea Weinberg Brekke  
Executive Director  
New Jersey Corporation for Advanced Technology  
c/o New Jersey Eco Complex  
1200 Florence Columbus Road  
Bordentown, NJ 08505  
609 499 3600 ext. 227  
[rwbrekke@njcat.org](mailto:rwbrekke@njcat.org)

John H. Schroeder, P.E.  
President  
HydroGlobe  
612 River Street  
Hoboken, NJ 07030  
201 656 2100  
[jschroeder@hydroglobe.com](mailto:jschroeder@hydroglobe.com)

Richard S. Magee, Sc.D., P.E., DEE  
Technical Director  
New Jersey Corporation for Advanced Technology  
c/o Carmagen Engineering Inc.  
4 West Main Street  
Rockaway, NJ 07866  
973 627 4455  
[rsmagee@njcat.org](mailto:rsmagee@njcat.org)

Manny Patel  
Office of Innovative Technology and Market Development  
NJ Department of Environmental Protection  
PO Box 409  
401 East State Street  
Trenton, NJ 08625  
609 292 0231  
[manish.patel@dep.state.nj.us](mailto:manish.patel@dep.state.nj.us)

Xiaoguang Meng, Ph.D.  
Associate Professor  
Center for Environmental Engineering  
Stevens Institute of Technology

Hoboken, NJ 07030  
201 216 8014  
[xmeng@stevens-tech.edu](mailto:xmeng@stevens-tech.edu)

Michael Winka  
Office of Innovative Technology and Market Development  
NJ Department of Environmental Protection  
401 East State Street  
Trenton, NJ 08625  
609 984 5418  
[mike.winka@dep.state.nj.us](mailto:mike.winka@dep.state.nj.us)

## 2. Evaluation of the Applicant

### 2.1 Corporate History

HydroGlobe, an innovative supplier of highly effective, low-cost technology to remove arsenic and heavy metals from drinking water and wastewater, was founded by engineers and scientists from the Center for Environmental Engineering at Stevens Institute of Technology in 2001. Prior to 2001, Stevens personnel did extensive work in Bangladesh, creating the first arsenic free village in that country using a version of this FerriMet technology. In 1997, a system using FerriMet was installed and is still operating successfully, removing arsenic from a superfund contaminated groundwater site in Texas.

### 2.2 Organization and Management

HydroGlobe is located in Hoboken, New Jersey on the Stevens Institute of Technology campus, adjacent to the Center for Environmental Engineering. John H. Schroeder, P.E., is HydroGlobe's only full-time employee. HydroGlobe employs several part-time consultants, including several Stevens Institute of Technology faculty. Current staffing is between two and three full-time equivalents. This staff is leveraged by the use currently of a commissioned sales agent; agreements are in negotiation with two other potential agents. In the manufacturing area, agreements are being negotiated with three equipment manufacturers, each specializing in various sizes of equipment, and all of whom service the municipal market with other products similar in equipment concept to the FerriMet product. One such agreement with a fourth company is already in place, and has led to joint proposals at several locations.

### 2.3 Operating Experience with Respect to the Proposed Technology

HydroGlobe's operating experience with the FerriMet process is limited. The most extensive experience has been in conjunction with the Hopewell, NJ demonstration testing. (See Section 5.2) and with a system installed in 1997 in Texas to remove arsenic from contaminated groundwater at a superfund site.



## 2.4 Patents

The patent-pending FerriMet direct coprecipitation filtration process combines proven methods of iron and sand filtration with innovative activation techniques. The technology is effective in the removal of arsenic and other heavy metals such as chromium, mercury, cadmium and selenium.

## 2.5 Technical Resources Staff and Capital Equipment

HydroGlobe maintains a close, collaborative working relationship with the Center for Environmental Engineering (CEE). The Center develops environmental technology for remediation and abatement of pollution in water, soil, and air, and clean technology that eliminates or minimizes the environmental impact of industrial activities. CEE operates the James C. Nicoll, Jr. Environmental Laboratory, a state-of-the-art experimental facility with process development and analytical capabilities. The Nicoll Laboratory and CEE faculty and staff provide the equipment and intellectual resources for HydroGlobe's treatability studies and technology optimization.

## 3. Treatment System Description

The FerriMet direct coprecipitation filtration process involves injection of small amounts of coagulants (and oxidants if needed) such as ferric chloride into water and subsequent filtration. The system consists of mainly a sand filter and a chemical pump(s). The process is designed to remove heavy metals (e.g., arsenic) from water to trace levels. Ferric chloride injected into the water hydrolyzes rapidly to form ferric hydroxide. The fresh hydroxide has a high capacity for removal of arsenic and other heavy metals through coprecipitation and adsorption. Arsenic is converted from soluble to particulate forms and is subsequently removed by the sand filter. The filters are regenerated by backwash using water. The backwash cycle can be triggered by a pressure drop across the filter or by a timer.

The removal of arsenic by the FerriMet process is affected mostly by three chemical parameters, including arsenic species, water pH, and the presence of coexisting anions (primarily silicate and phosphate). The fresh ferric hydroxide has very high removal capacity for arsenate [As(V)] and moderate removal capacity for arsenite [As(III)] in a neutral pH range. Arsenic in some groundwater exists as As(III). In order to improve the removal of arsenic, oxidants such as chlorine, hyperchlorite, peroxide, and permanganate, are used to convert As(III) to As(V). The oxidants can be readily injected into the FerriMet treatment process if they are needed. The removal of As(V) by ferric hydroxide decreases when the water pH increases above the neutral range. Therefore, pH adjustment is often required when the water pH is greater than 8. The pH adjustment can be easily achieved by injecting hydrochloric acid in-line into the water prior to the filter.

The design of the FerriMet system such as, locations of chemical injection ports, grain size of the filter media, and depth of the filter bed, determine the efficiency of arsenic removal, duration of the filtration run, and filtration and backwash flow rates. All the parameters in the FerriMet system are optimized to achieve efficient arsenic removal at very competitive costs.

The ferric hydroxide residuals generated in the FerriMet process are expected to pass the toxicity characteristic leaching procedure (TCLP) test for As and thus to be non-hazardous.

#### 4. Technical Performance Claim

**Claim** – The FerriMet process has been shown to achieve the reduction of arsenic (including As(III) and As(V) ) to below 5 µg/L in groundwater.

#### 5. Treatment System Performance

##### 5.1 Field Pilot Demonstration

Approximately 10 gallons of groundwater were received at HydroGlobe's laboratory at the Center for Environmental Engineering, Stevens Institute of Technology, Hoboken, NJ on July 24, 2001. The groundwater was collected from a nursery site in Delray Beach, Florida. The arsenic concentration was determined using a Zeeman Furnace Atomic Absorption Spectrometer (FAAS) (Varian SpectrAA-400). Total arsenic concentration in the sample was 700 µg/L; more than 115 µg/L of the arsenic existed in organic form. The water pH was 6.7 and iron concentration was approximately 1.0 mg/L.

Batch and column filtration tests were conducted in the laboratory to evaluate the effectiveness of the FerriMet process in removing arsenic from the groundwater. The filtration results demonstrated that the FerriMet process could remove arsenic from the groundwater to less than 20 µg/L with a single filter.

Pilot filtration tests were conducted at the nursery site during August 17 to 23, 2001. A pilot-scale filtration system consisting of a 4-in. diameter filter, approximately 8-ft high, and three chemical injection pumps was set up at the site. Filter media height in the column was approximately 3 ft. Contaminated groundwater was pumped into an equalization tank (a 55-gal drum). The water was then pumped through the filter. Chemicals (ferric chloride, hydrogen peroxide) were injected in-line into the groundwater prior to the filter. To simulate two filters in a series, the filtered water was collected into several plastic containers. The filter was backwashed with groundwater and used for a second treatment of the filtered water. Chemicals (ferric chloride, organic polymers) were injected during the second filtration. Filtration conditions, including doses of chemicals, filtration rate, and filter media were optimized.

During the filtration, effluent water samples were collected for the analysis of arsenic, turbidity, and pH. Arsenic was analyzed using a hydride generation method at the site to provide a quick estimate of As concentrations. Samples were also collected and analyzed for arsenic using FAAS at Stevens.

The arsenic concentration was reduced from approximately 700 µg/L to less than 250 µg/L during the first hour of filtration. Effluent arsenic concentration decreased to approximately 60 µg/L after 6 hours of filtration and then increased gradually. The effluent turbidity also showed a decrease in the first 5 hours and an increase afterward. The filter pressure remained at approximately 2.5 psi during the first 5 hours and increased to 4.7 psi after nearly 9 hours of

filtration. The results indicated that a single filtration stage could not reduce arsenic concentration to less than 60 µg/L.

When the filtered water was treated again with ferric chloride and organic polymers followed by filtration, the initial effluent arsenic concentration was 350 µg/L. This was because arsenic was adsorbed by the filter media during backwash with untreated groundwater, and approximately one bed volume of the untreated water was left in the filter after backwash. In full-scale treatment, the filters are back-washed with treated water to overcome this problem. The effluent arsenic concentration decreased to less than 50 µg/L after 1.5 hours and further decreased to less than 10 µg/L after 6 hours. No increase in arsenic concentration was observed during 7 hours of filtration. The effluent turbidity was less than 1 NTU, indicating very low particulate content in the filtered water. The pressure increased from 2.5 to 3.5 psi after 6 hours of filtration.

Further filtration tests were conducted at the site from October 3 to 6, 2001. A filtration system consisting of two filters in series was used. The system included one water pump and four chemical injection pumps. Ferric chloride was injected into both filters. Hydrogen peroxide and a polymer were injected into the first and second filter, respectively. The dosages of the chemicals were the same as used in the first field pilot filtration tests. Filtered water was used to backwash the filters.

The total arsenic concentration in the groundwater decreased from approximately 730 µg/L in August to approximately 440 µg/L in October 2001. Organic arsenic concentration was approximately 20 µg/L. The two filter FerriMet process reduced arsenic concentration from 440 µg/L to less than 3 µg/L. No increase in effluent arsenic concentration occurred during 7.5 hours of filtration. Mr. David C. Schulte, P.G., URS, Boca Raton, Florida, collected five effluent samples during testing on October 6, 2001, and sent them to an independent certified testing laboratory (Envirodyne, Inc., 4805 N.W., 2<sup>nd</sup> Avenue, Boca Raton, Florida) for arsenic analysis. The laboratory analysis (Envirodyne, 2001) reported that the four samples taken over the last five hours of the testing were all below the detection limit (DL – 10 µg/L) providing independent confirmation of FerriMet process performance.

## 5.2 Field Demonstration

The New Jersey Department of Environmental Protection's (NJDEP) Division of Science, Research and Technology funded a field pilot test of the FerriMet process at Hopewell, NJ through Stevens Institute of Technology. One of the Hopewell Borough wells, currently not in use, has elevated naturally occurring arsenic present (~40 µg/L). Hopewell Borough suspended operation of the well until such time as appropriate treatment measures can be implemented and agreed to participate in the demonstration project. The FerriMet treatment system, specifically designed for smaller water systems like Hopewell's, if demonstrated to be successful, could serve as a model for other community water suppliers requiring arsenic removal.

Filtration tests were conducted at Hopewell, NJ to verify the FerriMet process performance for the removal of arsenic from groundwater between December 4 and 23, 2001. A dual-media filter with an inside diameter of 14 inches, a sand bed of 24 inches, and an anthracite bed of 12 inches was used in the filtration tests. The filtration tests were conducted by the research assistants and

engineers from Stevens Institute of Technology. Raw water and filtered water samples were collected and sent to a certified laboratory (Seven Trent Services in Edison, NJ) for analyses of arsenic and general chemical parameters. The optimal filtration conditions established during the Initial Operations phase were: filtration rate of 3.0 gpm/ft<sup>2</sup>, ferric chloride dose at 1.5 mg-Fe/l, filtration duration of 48 hours backwash flow rate at about 10.8 gpm/ft<sup>2</sup> for 10 minutes.

The filtration testing was performed in accordance with the EPA/NSF ETV Protocol – “Protocol for Equipment Verification Testing for Arsenic Removal” (NSF International, 2000). Specifically, the procedures described in Chapter 3 “Coagulation and Filtration for Removal of Arsenic” were followed. The schedules of the tests are listed below. The tests included initial optimization, 24-hr. control filtration run (without chemical treatment), 320-hr. continuous filtration, and 48-hr. filtration at optimal conditions (within 320-hr.). During the field testing, the 48-hr. filtration run lasted for over 90 hr. in order to test a complete filtration run.

- |            |   |
|------------|---|
| Dec.4-5    | Optimization for chemical dose and flow rate<br>Sample: Analysis of As, turbidity, and pH.  |
| Dec 5-6    | 24-hr. control filtration run, without chemical addition<br>Sample: Raw and filtered water samples taken at 6, 12, 18, 24 hr. for analysis of As, turbidity, and pH.  |
| Dec 6-20   | 320-hr. continuous filtration<br>Sample (feed and filtered water): Temperature (d), pH (8 hr.), total alkalinity (d), hardness (w), UV254 absorbance (w), turbidity (d), Al (w), Fe (w), Mn (w), As(d), sulfate (w), DO (d), algae (w), true color (w). All weekly analysis to be performed by a certified lab, except UV254. (Could not find a lab to do UV254.) Total alkalinity sent out for analysis once a week. A continuous turbidity meter was installed on December 19. (Note: daily (d), weekly (w)). |
| Dec. 19-23 | 48-hr. filtration<br>Sample: 0, 1, 3, 6, 12, 18, 24, 30, 36, 42, 48 hr. 250-ml samples were taken of feed and filtered waters for analysis of arsenic by certified lab.   |

### 5.3 Verification procedures

HydroGlobe’s FerriMet process has been demonstrated on numerous groundwater samples collected throughout the United States in their laboratory treatability studies and in several field pilot demonstrations. While the data from these studies and demonstrations indicate the capability of the technology, the majority of these data do not meet the QA/QC and third party independence requirements for NJCAT verification. The one exception is the Hopewell Borough demonstration. Hence, the results from the Hopewell demonstration provide the basis for verification of HydroGlobe’s claim.

**Claim – The FerriMet process has been shown to achieve the reduction of arsenic (including As(III) and As(V) ) to below 5 µg/L in groundwater.**

In accordance with the EPA/NSF ETV Protocol, on December 5-6, 2001, a 24-hour filtration run was conducted prior to Verification Testing to determine if arsenic losses occur through the system. The results from this testing are shown in Table 2 and indicate essentially zero arsenic removal (i.e., the majority of the arsenic is soluble.) These data were analyzed in the Center for Environmental Engineering's Nicholl Laboratory.

**Table 2. Twenty-Four Hour Filtration Run (no chemical treatment)**

Date	Time	Raw Water			Filtered Water		
		As	Turbidity	pH	As	Turbidity	pH
		µg/L	NTU		µg/L	NTU	
05-Dec-01	18:30	-	-	-	-	-	-
06-Dec001	0:30	23.4	1.02	7.85	21.8	0.86	7.74
	6:30	23.0	0.95	7.87	21.2	0.72	7.76
	12:30	22.0	0.62	7.84	22.0	0.25	7.75
	18:30	22.3	0.63	7.85	22.0	0.26	7.75

During the Verification Testing period, raw and filtered water samples were taken once a week for comprehensive analyses of the physical and chemical properties by Seven Trent Services (777 New Durham Road, Edison, NJ, Tel: 732-549-3900). (Seven Trent Services, 2001 & 2002a). Eleven raw and filtered water samples were taken during the 48-hour filtration testing for analysis of arsenic by the certified laboratory. In addition to the analyses performed by the certified laboratory (Seven Trent Services, 2002b), split samples and additional samples were analyzed at the Nicholl Environmental Laboratory at Stevens Institute of Technology.

#### Characteristics of Hopewell Groundwater (near Well #6)

The characteristics of the groundwater are summarized in Table 3. Total arsenic content in the well water was between 34 and 38 µg/L. According to the speciation analysis performed at Stevens, approximately 10% of the total arsenic was As (III). The majority of the arsenic was As(V), which is less toxic and easier to remove than As(III). Because the concentration of As(III) in the groundwater was very low, no oxidant was used in the treatment.

**Table 3. Characteristics (Weekly) of the Raw and Filtered waters**

	12/13/01 sample		12/20/01 sample		Detection Limit (Seven Trent)
	Raw water	Filtered water	Raw water	Filtered water	
Al (µg/L)	N.D.	N.D.	N.D.	N.D.	125 (77.4)*
As (µg/L)	37.5	23.2	33.7	N.D.	6.4 (3.4)
Fe (µg/L)	57.8	684	374	N.D.	78.4 (39.7)
Mn (µg/L)	6	22.9	6.9	7.5	2.4 (2.9)
Hardness (mg/L)	154	156	156	154	5
Alkalinity(mg/L)	119	135	140	120	5
Color (pt./co.)	5	5	N.D.	N.D.	5
Sulfate (mg/L)	65.5	60.7	47.8	47.0	5
TOC (mg/L)	N.D.	N.D.	N.D.	N.D.	1

\*12/13/01 Detection Limits

## Verification Testing

During the 48-hour verification testing, the arsenic concentration in the raw water ranged from 33.4 to 39.8 µg/L (commercial laboratory using Inductively Coupled Plasma Atomic Emission Spectroscopy) and from 36.6 to 41.0 µg/L (Center for Environmental Engineering (CEE) laboratory using Furnace Atomic Absorption Spectrometer). NJDEP personnel sent a split sample taken at 15:30 on 2001-12-19 to an independent state laboratory that reported an arsenic level in the raw water of 41 µg/L and in the filtered water of 3.7 µg/L (Patel, 2002). The FerriMet process reduced the arsenic concentration to 4.3 µg/L or less (commercial laboratory) or 3.7 µg/L or less, with one exception (CEE laboratory). Table 4 shows the strong correlation between the Seven Trent Services and CEE results. (Note: The detection limit reported by the certified commercial laboratory was 3.6 µg/L, while CEE estimates an analytical error of  $\pm 50\%$  at an As concentration of 2 µg/L, making the two laboratory results essentially identical.) Table 5 summarizes the Hopewell test data and compares the Seven Trent and Stevens results during the 48-hour verification testing. For statistical analysis, the arsenic levels were assumed to be at the 3.6 µg/L detection limit for the Seven Trent N.D. reported values.

**Table 4. Arsenic Concentration Analyzed by Certified Laboratory and Stevens Institute of Technology.**

Date	Time	Total time (hr.)	Raw Water		Filtered Water	
			Commercial lab	SIT lab	Commercial lab	SIT lab
2001-12-19	14:30	0	38	39.6	4.3	5.6
	15:30	1	38	37.3	N.D.*	3.1
	17:30	3	37.5	38.1	N.D.	2.4
	20:30	6	39	39.1	N.D.	2.7
2001-12-20	2:30	12	37.7	40.1	N.D.	1.2
	8:30	18	39.8	40.1	N.D.	1.6
	14:30	24	35.1	36.9	N.D.	3.0
	20:30	30	35.5	39.1	N.D.	1.9
2001-12-21	2:30	36	33.4	39.8	N.D.	2.8
	8:30	42	35.5	39.1	N.D.	3.1
	14:30	48	36.1	39.0	4.3	3.7
	22:30	56		38.9		4.6
2001-12-22	10:30	68		39.8		4.0
	19:15	76.75		36.6		7.9
2001-12-23	10:25	91.92		41.0		3.5

\*N.D. – detection limit 3.6 µg/L

**Table 5. 48-Hour Verification Testing Summary**

	Commercial Lab	SIT Lab
Raw Water As Levels		
- Maximum	39.8	40.1
- Minimum	33.4	36.9
- Average	36.9	38.9
- 95 % Confidence Interval	38.2, 35.6	39.6, 38.2
Filtered Waster As Levels		
- Maximum	4.3	5.6
- Minimum	3.6	1.2
- Average	3.7	2.8
- 95 % Confidence Interval	3.7 $\pm$ 0.2	2.8 $\pm$ 0.8

After 68 hours of filtration the effluent turbidity increased from less than 0.2 to greater than 0.4 NTU, indicating some leakage of ferric hydroxide through the filter (Table 6). Meanwhile, effluent iron concentration increased from less than 50 to approximately 167 µg/L. Effluent arsenic concentration increased to approximately 7.9 µg/L after 77 hours of filtration.

### Water Treatment Residuals

After 92 hours of filtration, the sand filter was backwashed at a flow rate of 10.8 gpm for 10 min. Based on the total volume of water filtered (16,560 gal) in 92 h, the amount of raw water used for the backwash accounted for approximately 0.6% of water filtered. The backwash suspension was collected into a large container to allow the solids to settle for a few days. Approximately 16 L of the thickened suspension was collected. Total suspended solids in the suspension was 11.8 g/L. Soluble arsenic concentration in the suspension was 4.5 µg/L, which indicated that the supernatant could be discharged or pumped back into the filter. The suspension was filtered to remove free water for TCLP testing. Water content in the filter cake was 80%. The arsenic concentration in the TCLP leachate was 3.4 µg/L, which is well below the TCLP limit for a hazardous material. Hence the filter cake is suitable for non-hazardous landfill disposal. Total arsenic content in the dry solids was 8326 mg-As/kg dry solid.

The FerriMet process complexity and costs can be reduced if the backwash can be discharged directly to a POTW. Concerns have been raised about the impact on POTW operations from such a practice. Hence some additional testing on the Hopewell sludge was conducted to evaluate this impact. Specifically the following testing was conducted.

- TCLP on aged sludge (sample received at the commercial laboratory on 4/10/02) to determine if the leaching characteristics could negatively impact POTW sludge disposal. Result – Arsenic concentration in the TCLP leachate was 38 µg/L, well below the limit for a hazardous waste.
- Test of arsenic release from the sludge at pH=9. Results – The soluble arsenic concentration in the liquid was 40.0 µg/L, essentially the same as the untreated well water.

Based on the above test results, it should be acceptable to discharge the Hopewell backwash directly to the POTW. A final decision by the utility is pending.

In summary, testing on the Hopewell backwash and backwash residuals has shown that two options for residual disposal are technically feasible: 1) dewatering and disposal of the resulting filter cake to a non-hazardous landfill, and 2) direct discharge to a POTW. Ultimately it will be the local wastewater utility that decides if direct discharge is acceptable. Otherwise the solid residuals will have to be dewatered and disposed at a landfill.

**Table 6. Characteristics of Filtered and Raw Water during Verification Testing**

**Influent**

Date	Time	accu time	Raw water						
			pH	Alk(mg/L)	Temp (C)	DO (mg/L)	NTU	Fe (ppb)	As (ppb)
2001-12-19	14:30	0	7.90		12.5	1.35	0.21	42.7	39.6
	15:30	1	7.90	152	12.7	1.42	0.22	46.0	37.3
	17:30	3	7.88		12.6	1.12	0.21	10.86	38.1
	20:30	6	7.85		12.8	0.93	0.17	15.38	39.1
2001-12-20	2:30	12	7.84		13.0	0.92	0.25	5.32	40.1
	8:30	18	7.80	150	13.1	0.38	0.17	4.52	40.1
	14:30	24	7.73		12.7	0.92	0.16	4.98	36.9
	20:30	30	7.83		13.0	0.72	0.34	3.90	39.1
2001-12-21	2:30	36	7.81		13.1	0.90	0.18	6.72	39.8
	8:30	42	7.84	152	13.0	0.95	0.33	57.18	39.1
	14:30	48	7.81		12.8	0.59	0.19	58.58	39.0
	22:30	56	7.81		13.1	1.00	0.21	3.82	38.9
2001-12-22	10:30	68	7.79	154	13.1	0.18	0.11	6.26	39.8
	19:15	76.75	7.78		13.0	0.25	0.16	5.86	36.6
2001-12-23	10:25	91.92	7.85		12.3	0.94	0.13	2.68	41.0

**Effluent**

Date	Time	accu time	Filtered Water						
			pH	Alk(mg/L)	Temp (C)	DO (mg/L)	NTU	Fe (ppb)	As (ppb)
2001-12-19	14:30	0	7.64		12.6	0.97	0.13	197.6	5.6
	15:30	1	7.71	145	12.7	1.06	0.14	54.4	3.1
	17:30	3	7.69		12.6	0.98	0.13	28.7	2.4
	20:30	6	7.59		13.0	0.48	0.14	23.8	2.7
2001-12-20	2:30	12	7.57		13.0	-	0.20	32.5	1.2
	8:30	18	7.76	145	13.0	0.50	0.10	17.5	1.6
	14:30	24	7.54		12.7	0.61	0.08	42.5	3.0
	20:30	30	7.54		13.0	0.47	0.16	24.1	1.9
2001-12-21	2:30	36	7.58		12.9	0.48	0.18	58.1	2.8
	8:30	42	7.56	144	12.8	0.49	0.20	39.6	3.1
	14:30	48	7.60		12.8	0.40	0.15	137.1	3.7
	22:30	56	7.57		12.9	0.64	0.19	27.3	4.6
2001-12-22	10:30	68	7.57	148	12.9	0.30	0.48	162.4	4.0
	19:15	76.75	7.56		12.8	0.32	0.44	176.6	7.9
2001-12-23	10:25	91.92	7.56		12.9	0.48	0.55	35.2	3.5



## 6 Technical Evaluation Analysis

### 6.1 Verification of Performance Claims

Based on a review of the performance data from the Hopewell Borough field demonstration conducted in accordance with the EPA/NSF Protocol for Equipment Verification Testing for Arsenic Removal, sufficient data exists to support HydroGlobe's claim regarding the FerriMet process.

### 6.2 Limitations

The removal of As(V) by ferric hydroxide decreases when the water pH increases from 6 to 9. Therefore, pH adjustment is often required when the water pH exceeds 8. The pH adjustment can be achieved by injecting hydrochloric acid in-line into the water prior to the filter. Since ferric hydroxide has a very high removal for As(V), but only a moderate removal capacity for As(III) in this neutral pH range, As(III) should be oxidized to As(V) for efficient arsenic removal.

The presence of high silicate concentration adversely affects the removal of arsenic. Phosphate concentration in the U.S. groundwater is usually less than 0.1 ppm. The existence of phosphorous even at concentrations of less than 1 ppm can dramatically hinder the removal of arsenic. High dose of iron coagulants and pH adjustment may be needed to achieve sufficient removal of arsenic by the FerriMet process when silicate and phosphate anions are present in high concentrations. The FerriMet process also requires a higher dose of iron coagulant, and subsequent higher residuals to manage, as the arsenic concentration in the influent increases.

## 7. Net Environmental Benefit

The New Jersey Department of Environmental Protection (NJDEP or Department) encourages the development of innovative environmental technologies (IET) and has established a performance partnership between their verification/certification process and NJCAT's third party independent technology verification program. The Department in the IET data and technology verification/certification process will work with any New Jersey-based company that can demonstrate a net beneficial effect (NBE) irrespective of the operational status, class or stage of an IET. Per guidance developed by NJDEP Office of Innovative Technology as part of the Environmental Council of The States' (ECOS) Technology Acceptance and Reciprocity Partnership (TARP) workgroup the NBE is calculated as a mass balance of the IET in terms of its inputs of raw materials, water and energy use and its outputs of air emissions, wastewater discharges, and solid waste residues. Overall the IET should demonstrate a significant reduction of the impacts to the environment when compared to baseline conditions for the same or equivalent inputs and outputs. The NBE evaluation for the FerriMet technology was developed in two parts: as an energy balance and as a qualitative materials balance.

### a. Energy Balance

The FerriMet process uses power for chemical feed, to overcome pressure drop across the filter, and to backwash the filter. HydroGlobe estimates that for a 150 gpm (0.216 mgd) facility, with a

48 hour backwash cycle (432,000 gallons of feedwater per backwash cycle), 1.7 kWh will be required for chemical feed, 13.8 kWh to overcome pressure drop, and 0.6 kWh for each backwash cycle – a total of 15.1 kWh (0.035 kWh/1000 gal). (Note. If the precipitate is to be land-filled, then additional power will be consumed in dewatering the residuals.)

The only study that could be found that contained detailed energy requirements for a comparable process was prepared for the City of Albuquerque, New Mexico, Public Works Department (Chwirka, 1999). This study involved a detailed cost and energy evaluation of three technologies under consideration for treatment of arsenic in drinking water from the City's wells. The three technologies evaluated – ion exchange, coagulation/microfiltration, and activated alumina, have been proven to remove arsenic from drinking water. Data for the coagulation/microfiltration process was chosen for comparison since it is essentially the same process, with the microfiltration system performing the same function as the sand filter. For a 1 mgd capacity plant, the annual energy usage for the arsenic removal was calculated to be 29,275 kWh. (Note. The plant evaluated had a 500-micron strainer to remove sand or sediment (1,190 kWh/yr.) and a capability to dewater the solids to approximately 20 percent solids to pass the paint filter test prior to landfilling (4,895 kWh/yr.). The energy requirements for these two unit processes were subtracted from the total to facilitate an equal comparison.) The resulting energy requirement for treatment by coagulation/microfiltration is 0.064 kWh/1000 gal. Hence the annual energy savings of the FerriMet process over coagulation/microfiltration on a plant treating 150 gpm is 2290 kWh.

Based on emission factors supplied by NJDEP Office of Innovative Technology for electricity generation for the Pennsylvania, Jersey and Maryland (PJM) power pool, Table 7 provides the projected avoided emissions for the FerriMet process as compared to the coagulation/microfiltration system.

It should be noted that since the technology to treat and control arsenic in drinking water would be new, and require additional process equipment to any current drinking water treatment facility, the air emissions resulting from implementation of this new technology would increase. The innovation and uniqueness of the FerriMet process provides for a direct coprecipitation filtration process that allows for a smaller technology footprint and a minimization of these new air emissions over other existing or innovative arsenic treatment technologies.

**Table 7 – Pounds of air Emissions per 1000 Gallons of Treated Drinking Water**

Air Constituent	FerriMet	Coagulation/Microfiltration	Avoided Emissions
Carbon Dioxide (CO <sub>2</sub> )	0.05324	0.09734	0.04494
Nitrogen Oxides (NO <sub>x</sub> )	0.00023	0.00042	0.00019
Sulfur Dioxide (SO <sub>2</sub> )	0.00010	0.00018	0.00008
Mercury (Hg)	2.0E-09	3.0E-09	1.0E-09

*Emission factors are PJM Annual average emissions include ozone and nonozone season for peak and off-peak calculated for 2002 "OTC Emissions Reduction Workbook – User's Manual" prepared by Synapse Energy Economics May 2002 Draft.*

If the arsenic treatment precipitate is to be landfilled, then additional power will be consumed in dewatering the residuals. Based on the Albuquerque study cited above, the power need for dewatering is approximately 0.0049 KWh/1000 gal. The additional air emissions from the dewatering power requirement would need to be included in the energy balances for both technologies; however, the total avoided emissions would be the same.

#### b. Materials Balance

The more important NBE results from removing the arsenic from the drinking water influent and concentrating the arsenic in the filter cake that is ultimately sequestered from direct human intake. The filter cake from the FerriMet process, based on the test data, is a relatively insoluble residual. The filter cake could be suitable for non-hazardous landfill disposal, since the test data documents that the leachate from the residual would be significantly below the TCLP regulatory threshold of (5 mg/l) for arsenic. The treatment of arsenic in drinking water and sequestering it in an insoluble residual form results in significantly less arsenic available to the environment.

During the 48-hour verification testing period, the FerriMet process removed over 1100 mg of arsenic from the Hopewell Boro drinking water and concentrated it in the residuals. If the backwash is discharged directly to a POTW, the arsenic from the backwash solids, which is now relatively tightly bound in the solid (as compared to the soluble form in the drinking water), will add to the existing arsenic in the POTW sludge. Depending on the POTW sludge disposal option chosen, e.g., land application, landfill, incineration, a different fraction of this arsenic will be returned to the environment.

The general NBE mass balance flow diagram of the FerriMet process is shown in Figure 1 as an illustrative example. The environmental fate of the arsenic in the inlet drinking water is traced for a municipal distribution system similar to Hopewell Boro with and without the FerriMet treatment process. This mass balance uses a total arsenic influent to the system of 1000 mg that is similar to the value removed in the New Jersey full-scale demonstration. This value is for illustrative purpose and the total arsenic in the system will depend on the concentration of arsenic in the groundwater, the drinking water system flow rate, the overlap of drinking water system service area to the POTW service area, the ratio of drinking water discharge to the POTW or septic system and losses in the systems.

In the “No Arsenic Treatment” qualitative mass balance flow diagram, 95 percent of the potable water is discharged to a POTW and 5 percent through individual septic systems. In this example of 1000 mg of total arsenic in the drinking water system, 50 mg would be discharged to groundwater and 950 mg would be discharged to surface water. The influent and effluent concentrations at the POTW/septic system are assumed to be equal since secondary or biological treatment is not effective for removal of arsenic. Only a very small fraction of the arsenic (in ppm) in the drinking water discharge to the POTW or septic system is transferred to the sludge.

It should be noted that currently Hopewell Boro is served by three potable wells. Two of these wells are significantly below the current arsenic drinking water standard. The third well that was the subject of the New Jersey full-scale demonstration in this verification is not in service. The discharges in this mass balance flow diagram are qualitative and for illustrative purposes only.

In the “Arsenic Treatment” qualitative mass balance flow diagram based on the data from the New Jersey full scale demonstration, at a minimum, 90 percent of the soluble arsenic is removed by the FerriMet process and sequestered in the residual solids. This arsenic is rendered insoluble when compared to the soluble arsenic in the drinking water. The potable water use discharges after the FerriMet process is equivalent to the “No Arsenic Treatment” scenario above: 5 percent of the water is eventually discharged from septic systems and 95 percent of the water goes to the POTW. Effluent and influent arsenic concentration’s from the POTW/septic systems are assumed equal (no tertiary treatment) and hence no arsenic is removed with the POTW/septic system sludge. Consequently, the FerriMet process in this evaluation reduces the arsenic discharge to ground and surface water by 90 percent. Ultimately the amount of arsenic available to the environment will depend on the overall residual handling options.

Based on the removal of available arsenic from direct human intake and the sequestering of that arsenic into an insoluble residual that is less available to the environment, the FerriMet process meets the definition for an NBE.

#### 8. Costs

The NJDEP has requested that capital and operating costs for the FerriMet process be included in the NJCAT Technology Verification Report. HydroGlobe has supplied NJCAT cost data and these are shown in the Appendix. NJCAT cannot independently verify these costs; consequently the Appendix should not be taken as part of the NJCAT verification.

## 9. References

- Chwirka, J.D. (1999) Arsenic Treatment Evaluation Report, prepared for the City of Albuquerque, Public Works Department, by CH2MHill.
- Chwirka J.D., Thomson, B.M., and Stomp III, J.M., (2000) Removing Arsenic from Groundwater, J. AWWA, **92**, 79-88.
- Envirodyne, Inc. (2001). Certificate of Analysis – Project 42922-004 Petersen Nursery. Report 2001/1017. October 11, 2001.
- Meng X., Bang S., and Korfiatis, G., (2000) Effects of Silicate, Sulfate, and Carbonate on Arsenic Removal by Ferric Chloride, Wat. Research, **34**, 1255-1261.
- Meng, X (2002). Private communication.
- Patel, M (2002). Private communication.
- NSF International (2000). EPA/NSF Protocol for Equipment Verification Testing for Arsenic Removal. NSF International 40CFR35.6450. Chapter 3: EPA/NSF ETV Equipment Verification Testing Plan – Coagulation and Filtration for Removal of Arsenic.
- Seven Trent Services (2001). Laboratory Results: Job No. R883 - Hopewell/NJDEP. December 31, 2001.
- Seven Trent Services (2002a). Laboratory Results: Job No. S176 - Stevens Institute of Technology. January 16, 2002.
- Seven Trent Services (2002b). Laboratory Results: Job No. S412 – Hopewell/NJDEP. January 22, 2002.

## Appendix

### Capital and Operating Costs (provided by HydroGlobe)

#### Capital Costs

The capital costs of FerriMet systems will depend on a variety of factors, including capacity, water characteristics, and requirements for the backwash disposition. A prototype system (135 gpm) such as that for Hopewell, with a simple design, water without the need for pretreatments, and with backwash discharged to a POTW will have a cost of about \$100,000, not including site work (equipment only). A similar system, at 1000 gpm, would cost about \$500,000, and at 4000 gpm about \$1,900,000. Pretreatment capability would add 5-10% for each treatment needed (i.e. pH adjust or oxidant), and the need to filter the backwash solids and recycle backwash water could add 30-50%.

#### Chemical Costs

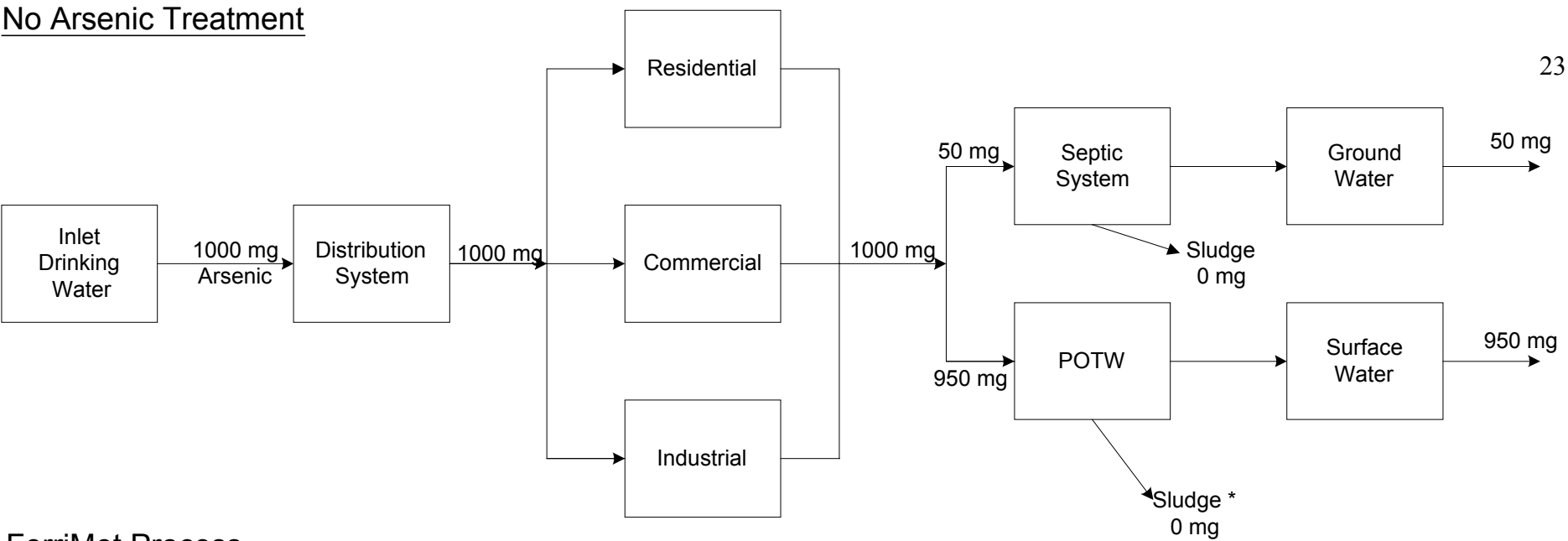
The operating (chemical) costs of FerriMet systems will depend on several factors also, including water characteristics, arsenic levels, and sludge disposition. Again for a simple system like Hopewell with 40 ppb arsenic, no other issues, the treatment chemical costs would be about \$0.02 per 1000 gallons. If sludge needed to be recovered and sent to a nonhazardous landfill, this could add \$0.002 per 1000 gallons. Waters very high in silicates or phosphates might require 5 times the treatment chemicals of Hopewell, and hence 5 times each of these costs. Lower arsenic levels would lead to costs about 10-20% below Hopewell. Pretreatment chemicals for pH or oxidant would add less than \$0.005 per 1000 gallons each, but depend on the specific issues involved.

#### Treatment Costs/1000 gal. (Hopewell-135 gpm)

Capital cost <sup>1</sup> (7%, 20 yrs.)	\$0.133
Chemical cost	\$0.020
Energy Cost (\$0.08/kWh)	<u>\$0.003</u>
Total	\$0.156

1 – Assumes annual full-plant capacity utilization ( $71 \times 10^6$  gallons)

No Arsenic Treatment



FerriMet Process

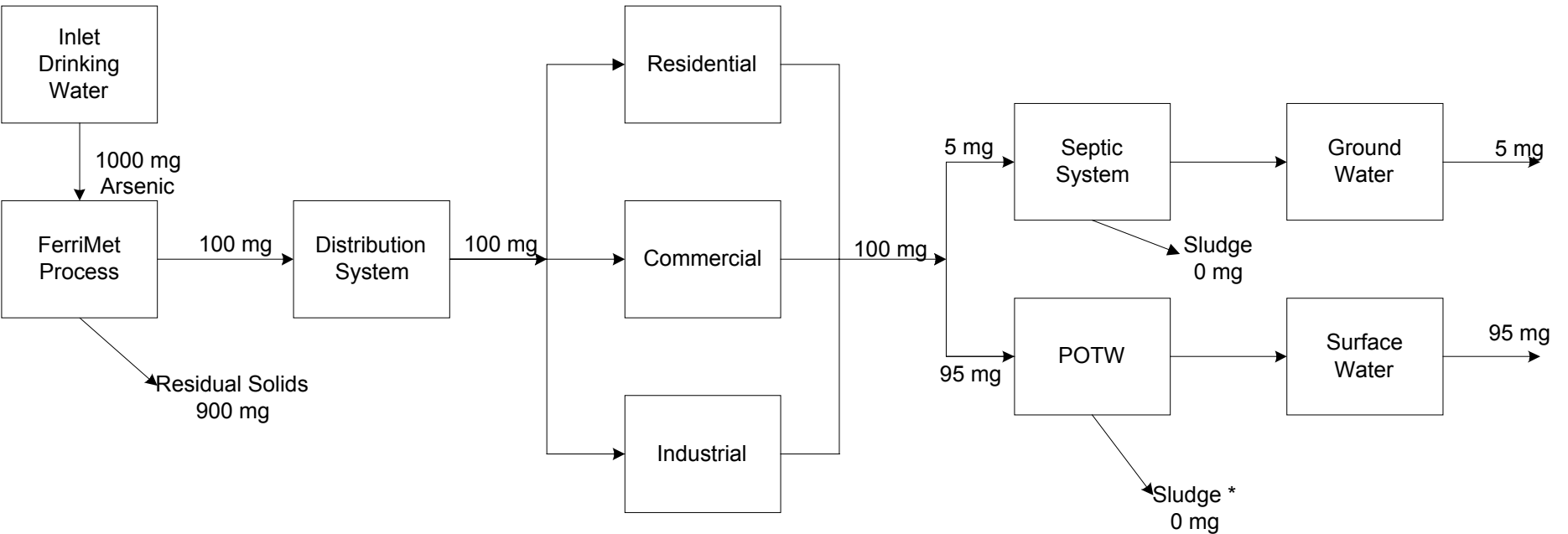


Figure 1- Environmental Fate of Arsenic With/Without FerriMet Treatment Process  
(Numerical Values are for Illustration Purposes Only. Actual Values are Site Specific)

\* A small fraction of the dissolved arsenic concentrates in the sludge. This measurable value is not zero and is on the order of less than 10 mg/kg.